



# Energy consumption, fuel substitution, technical change, and economic growth: Implications for CO<sub>2</sub> mitigation in Egypt

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## ABSTRACT

Energy consumption propels economic growth but the level of CO<sub>2</sub> emissions associated with a fossil-dominated energy structure raises concerns for the fight against climate change. To draw consensus, this study develops a translog-causality-based model in order to study causation between electricity, natural gas, petroleum, and economic growth in Egypt. In addition, the models' results are used to estimate the substitution possibilities between various energy pairs and to subsequently test the CO<sub>2</sub> mitigation benefits arising from fuel substitution. Results support a bidirectional relationship between all energy types and economic growth in Egypt and suggest, also, that these energy types are substitutes. Although technical progress is estimated to be a bit slow (varying between 4.5% and 7.5%), there appears to be substantial CO<sub>2</sub> emissions mitigation benefits from fuel substitution amounting to reductions in the range of 1.5 and 2.2 million metric tons under a 5% investment scenario and 2.5 and 4.5 million metric tons under a 10% investment scenario. These results have broader implications for energy conservation policies and industrial merger policies in developing countries. Moreover, by studying technical change, insights are provided on future CO<sub>2</sub> mitigation potential driven by energy efficiency.

## 1. Introduction

A large number of studies have suggested that the consumption of energy is important for a country's economic growth. However, the associated CO<sub>2</sub> emissions from energy usage have become an issue of concern, especially as climate change persists. In fact, the International Energy Agency (IEA) reports that about 49% of worldwide CO<sub>2</sub> emissions come from energy utilization and developing countries, due to high energy intensity as a result of their transition towards industrialization and urbanization, are expected to account for a greater portion of energy-related CO<sub>2</sub> emissions.

There are three prominent ways through which governments could reduce the rate of CO<sub>2</sub> emissions. First, this could be done through energy efficiency measures like the application of new technologies such as insulation upgrades, furnaces of high efficiency, compact fluorescent bulbs, etc. The second approach to mitigation could be through the expansion of investment in clean energy sources like wind, solar, geothermal, biomass, hydro, etc. Finally, governments could also consider instruments like carbon taxes, emissions trading schemes, carbon capture and storage, etc. (Wesseh and Lin, 2016d).

Egypt, as surrogate for a developing open economy in transition, is no exception to this debate. The levels of energy consumption and CO<sub>2</sub>

emissions have soared with the rate of growth and expansion of the economy (Fig. 1). It also appears clear from Fig. 1 that energy consumption and CO<sub>2</sub> emissions have a direct co-movement – rising and falling at similar points (these break points are obvious in the years 2005 and 2008). This co-movement between energy consumption and CO<sub>2</sub> emissions is not surprising considering that Egypt is Africa's largest oil consumer with about 41% of electricity and 45% of primary energy sourced from oil (EIA, 2014). These conditions make Egypt a suitable case in which to study the mitigation potential of inter-fuel substitution and how energy consumption really impacts on economic growth.

As we show in the next section, the problem of energy consumption and economic growth has been addressed by use of several methods ranging from Granger causality approaches to Sim's technique, from Cointegration methods to Error Correction Models (ECM) and Vector Error Correction Models (VECM), from Multivariate Vector Autoregressive (VAR) models to Autoregressive Distributed lags (ARDL) bounds techniques, and from Toda–Yamamoto method to bootstrap empirical distributions (Omri, 2014). Even though there have been numerous contributions to the literature from the use of these different modeling approaches, these have also come with mixed results. This inconclusive nature of the literature becomes an issue of concern especially considering the arbitrary nature in which variables are

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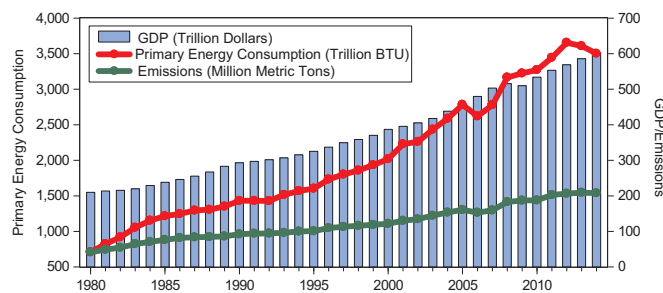


Fig. 1. Energy consumption, emissions, and GDP in Egypt (1980 – 2014).

selected for these models. In other words, commonly used approaches to causality analysis in the energy – economy literature do not clearly define a definite theoretical relationship between output and input, and hence, paves the way for either omitted variable biased or over-defined models. Furthermore, energy substitution effects due to environmental regulations, price and demand changes are neglected. For these reasons, further insights based on improved modeling would provide opportunities.

Therefore, in order to address these problems, we develop a translog-causality-based approach<sup>1</sup> to energy – economy modeling in order to study the direction of causation between various energy forms and economic growth. Subsequently, these results are used to estimate the substitution possibilities of various energy forms and to quantify the mitigation potential arising from energy substitution. Our applied production approach does not only define a definite relationship between output and input, but it also incorporates the interactions among various energy forms and the level of technical progress with which these inputs are used. Against these backdrops, the present study serves to contribute to the literature not only in terms of Egyptian energy policy design, but also with regards to methodological issues inherent in the energy – economy literature. For we incorporate dynamic components into the traditional translog production model.

The remainder of this study proceeds as follows: The second section introduces the literature and how the problem has been addressed. The third section describes the dataset. Section four presents the model framework and the procedures used for deriving various estimates. Section five presents the results and discussion. Section six draws the conclusions.

## 2. Literature review

In terms of how energy consumption affects economic growth, a number of contributions have emerged. A review of this literature shows that several approaches have been employed to address the problem. From Granger causality approaches to Sim's technique, from Cointegration methods to Error Correction Models (ECM) and Vector Error Correction Models (VECM), from Multivariate Vector Autoregressive (VAR) models to Autoregressive Distributed lags (ARDL) bounds techniques, from Toda–Yamamoto method to bootstrap empirical distributions. There have been mixed results from these diverse approaches (Omri, 2014).

There are studies that evaluate how energy consumption on the aggregate affects the economy. According to Wesseh and Lin (2016a), results are quite mixed with 29% of the studies pointing to a unidirectional causality from energy to economic growth, 27% showing bidirectional relationship between energy and economic growth, 23% supporting a unidirectional causality from growth to energy, and 21% suggesting no form of relationship between energy and growth.

As opposed to aggregate primary energy, some contributions have

used total electricity to represent energy and to examine how electricity uses impact on economic growth. A review of these results shows 40% support for energy to growth, 33% support for a bidirectional relationship, and 27% support for growth to energy. For country-specific studies which use electricity to represent energy use, there is no evidence of neutrality between energy and growth.

The effects of nuclear energy on economic growth have also been considered. 60% of existing evidence supports no form of relationship between nuclear energy and growth while 40% suggests a unidirectional relationship from nuclear energy to growth. No evidence of bidirectional relationship and conservational relationship has been found.

Few authors have attempted to study how renewable energy consumption impacts on economic growth. Again, results are quite mixed and show 40% support for no relationship between renewable energy and growth, 40% support for growth to energy, and 20% support for energy to growth. No support for the feedback hypothesis has been found. For detailed list of international studies, interested readers are referred to Omri (2014) and Wesseh and Lin (2016a).

In terms of African countries in particular, be it single-country or multi-country study, results have supported all hypotheses. A detailed review of energy consumption – economic growth studies for Africa since the year 1996 is presented in Table 1.

Quite a great number of contributions focusing exclusively on African countries have suggested a unidirectional causality running from energy consumption to economic growth (or growth hypothesis). These studies point to the importance of energy for growth and development suggesting that energy conservation policies aimed at reducing the levels of CO<sub>2</sub> emissions would constrain economic growth. Contributions in this category have employed diverse approaches. For instance, Wolde-Rufael (2009) utilizes the Toda and Yamamoto approach to analyze the impact of energy consumption on economic growth in 17 African countries. Odhiambo (2009b) use the Autoregressive Distributed lag modeling technique to study the impact of energy consumption on the economy of Tanzania over the period 1971–2006. Akinlo (2009) employs cointegration analysis to examine how energy use impacts on the Nigerian economy over the period 1980–2006. Mensah and Wolde-Rufael (2010) adopt the Autoregressive Distributed lag technique to evaluate the impacts of energy consumption on the South African economy over the period 1965–2006. Al-mulali and Sab (2012) use panel cointegration model to determine how energy consumption affects economic growth in 30 African countries over the period 1980–2008. Ouedraogo (2013) use panel cointegration model to study the impact of energy consumption on economic growth in the ECOWAS region over the period 1980–2008. Kumar and Kumar (2013) employ the Autoregressive Distributed lag modeling technique to test the influence of energy use on economic growth in South Africa and Kenya. Mensah (2014) applies the Autoregressive Distributed lag technique to examine how energy use affects economic growth in 6 African economies. Lin and Wesseh (2014) employ the Bootstrap testing technique to evaluate the impact of energy consumption on the South African economy over the period 1971–2010. Aïssa et al. (2014) adopt a Panel Error Correction modeling approach to study the impact of energy consumption on economic growth in 11 African countries over the period 1980–2008. Another contribution which shows a unidirectional causality running from energy consumption to economic growth in an African country is Kebede et al. (2010).

On the contrary, one contribution on African countries (Richard, 2012) finds that causality runs from economic growth to energy consumption (conservation hypothesis) and not the other way around. These authors argue that it is the growth of the economy that gives rise to energy use. Richard (2012) employs the Hidden cointegration modeling technique to test the impacts of energy consumption on 12 African countries over the period 1971–2008. Furthermore, to the conservation hypothesis, some results also pointed to the growth hypothesis.

<sup>1</sup> The static production model has mainly been used to estimate energy substitution effects (e.g. Lin and Wesseh, 2013a; Wesseh et al., 2013).

**Table 1**

A review of energy consumption and growth nexus for Africa.

Source: Wesseh and Lin (2016a); Authors own compilation

| Author                         | Country                | Period    | Method                 | Conclusion          |
|--------------------------------|------------------------|-----------|------------------------|---------------------|
| Ebohon (1996)                  | Nigeria and Tanzania   | 1960–1984 | Granger causality      | Feedback hypothesis |
| Jumbe (2004)                   | Malawi                 | 1970–1999 | Error Correction       | Feedback hypothesis |
| Wolde-Rufael (2005)            | 19 African countries   | 1971–2001 | Toda and Yamamoto      | All four hypothesis |
| Wolde-Rufael (2006)            | 17 African countries   | 1971–2001 | Toda and Yamamoto      | All four hypothesis |
| Akinlo (2008)                  | 11 African Countries   |           | ARDL                   | All four hypothesis |
| Wolde-Rufael (2009)            | 17 African countries   |           | Toda and Yamamoto      | Growth hypothesis   |
| Odhiambo (2009a)               | South Africa           | 1971–2006 |                        | Feedback hypothesis |
| Odhiambo (2009b)               | Tanzania               | 1971–2006 | ARDL                   | Growth hypothesis   |
| Akinlo (2009)                  | Nigeria                | 1980–2006 | Cointegration          | Growth hypothesis   |
| Menyah and Wolde-Rufael (2010) | South Africa           | 1965–2006 | ARDL                   | Growth hypothesis   |
| Esso (2010)                    |                        |           |                        |                     |
| Odhiambo (2010)                |                        |           |                        |                     |
| Ouedraogo (2010)               | Burkina Faso           | 1968–2003 | ARDL                   | Feedback hypothesis |
| Kebede et al. (2010) <         | 20 African countries   |           |                        | Growth hypothesis   |
| Kouakou (2011)                 | Cote d'Ivoire          | 1971–2008 | Error Correction       | Feedback hypothesis |
| Eggoh et al. (2011)            | 21 African countries   | 1970–2006 | Panel Cointegration    | Feedback hypothesis |
| Al-mulali and Sab (2012)       | 30 African countries   | 1980–2008 | Panel Model            | Growth hypothesis   |
| Wesseh and Zoumara (2012)      | Liberia                | 1980–2008 | Bootstrap tests        | Feedback hypothesis |
| Tamba et al. (2012)            | Cameroon               | 1975–2008 | Error Correction       | Feedback hypothesis |
| Kahsai et al. (2012)           |                        |           |                        |                     |
| Richard (2012)                 | 12 African countries   | 1971–2008 | Hidden cointegration   | Conser & growth     |
| Wandji (2013)                  | Cameroon               |           | Error Correction       | Growth & Neutrality |
| Solarin and Shahbaz (2013)     | Angola                 | 1971–2009 | ARDL                   | Feedback hypothesis |
| Behmiri and Manso (2013)       | 23 African countries   | 1985–2011 | Panel causality        | Feedback hypothesis |
| Fuinhas and Marques (2013)     | Algeria and Egypt      | 1965–2010 |                        | Feedback hypothesis |
| Ouedraogo (2013)               | ECOWAS countries       | 1980–2008 | Panel Cointegration    | Growth hypothesis   |
| Kumar and Kumar (2013)         | South Africa and Kenya |           | ARDL                   | Growth hypothesis   |
| Bélaïd and Abderrahmani (2013) | Algeria                | 1971–2010 | Error Correction       | Feedback hypothesis |
| Mensah (2014)                  | 6 African economies    |           | ARDL                   | Growth hypothesis   |
| Lin and Wesseh (2014)          | South Africa           | 1971–2010 | Bootstrap tests        | Growth hypothesis   |
| Aïssa et al. (2014)            | 11 African countries   | 1980–2008 | Panel Error Correction | Growth hypothesis   |
| Adams et al. (2016)            | 16 African Countries   | 1971–2013 | PVAR                   | Feedback hypothesis |
| Bildirici and Özaksoy (2016)   | 8 African Countries    | 1980–2013 | ARDL                   | Growth & Feedback   |
| Bah and Azam (2017)            | South Africa           | 1971–2012 | Toda and Yamamoto      | Neutrality          |

Interestingly, a good number of studies have suggested a two-way relationship between energy consumption and economic growth. In other words, energy use causes economic growth and economic growth causes energy use at the same time. This implies that energy is also important for growth and development of the economy and, at the same time as the economy grows, more and more energy becomes necessary to feed economic activities. Using diverse approaches as will, the following contributions have supported this feedback hypothesis: Ebohon (1996) uses traditional Granger causality techniques and examines how energy consumption impacts the economies of Nigeria and Tanzania over the period 1960–1984. Jumbe (2004) uses Error Correction Method (ECM) to test the effect of energy utilization on the Malawian economy from the period 1970–1999. Ouedraogo (2010) applies the Autoregressive Distributed lag (ARDL) approach to gauge the impact of energy use on the economy of Burkina Faso over the period 1968–2003. Kouakou (2011) adopts the Error Correction technique to address the links between energy use and economic growth in Cote d'Ivoire over the period 1971–2008. Eggoh et al. (2011) employ panel cointegration technique for the purpose of studying the influence of energy consumption on 21 African countries over the period 1970–2006. Wesseh and Zoumara (2012) use the Bootstrap empirical distribution to test the impact of energy consumption on the Liberian economy over the period 1980–2008. Tamba et al. (2012) use the Error Correction model in order to study the impact of energy consumption on the Cameroonian economy over the period 1975–2008. Solarin and Shahbaz (2013) apply the Autoregressive Distributed lag approach to study the impact of energy consumption on the economy of Angola over the period 1971–2009. Behmiri and Manso (2013) use the panel causality framework to study the impacts of energy consumption on 23 African countries over the period 1985–2011. Bélaïd and Abderrahmani (2013) apply the Error Correction model to evaluate the manner in which

energy consumption affects economic growth in Algeria over the period 1971–2010. Adams et al. (2016) use the pairwise Vector Autoregressive framework to examine the impacts of energy consumption on 16 African Countries over the period 1971–2013. Other studies on African countries which support a feedback relationship between energy consumption and economic growth are Odhiambo (2009a) and Fuinhas and Marques (2013).

There are also contributions on Africa which suggest no form of causality between energy consumption and economic growth. Bah and Azam (2017) adopts the Toda and Yamamoto modeling technique to study the effect of energy consumption on economic growth in South Africa over the period 1971–2012. The authors found no causality relationship between the two variables. Wandji (2013) uses Error Correction models and draws the same conclusion for Cameroon.

There are other multi-country studies for African countries in which all four hypotheses are supported. These are: Wolde-Rufael (2005) using Toda and Yamamoto modeling technique for 19 African countries over the period 1971–2001; Wolde-Rufael (2006) using Toda and Yamamoto modeling techniques for 17 African countries over the period 1971–2001; and Akinlo (2008) using the Autoregressive Distributed lag modeling technique for 11 African Countries.

The applied methods in the above studies for African countries are representative of various approaches that have been used in this literature. Despite increasing recognition of energy as an important input of production, to the best of our knowledge, a production-based causality approach has never been applied. Consequently, the substitution effects happening among various inputs and the technological progress with which these inputs are used have been ignored. In addition, the relationship between oil, gas, electricity, and economic growth and the mitigation potential of substituting among these inputs has never been estimated for Egypt before. Hence, this study provides new insights for

the literature.

### 3. The data

Yearly observations on Egypt's consumption of electricity, natural gas, and petroleum are used to represent energy inputs. Aggregate output, labor supplied, and gross capital formation describe three other inputs employed in this paper. These data are sampled from the period 1980–2016. All variables are adjusted appropriately to allow for robustness of results (Lin and Wesseh, 2013b, 2013c). For instance, in order to ensure that the production model satisfies all regularity conditions, all the time series in this study have been normalized around the sample mean before taking logs. To do this, we divide all the time series by their sample means (Wesseh and Lin, 2016c).

The energy type data are collected from the US Energy Information Administration (IEA) database. We collect observations on capital, labor, and output from the World Bank. We derive capital stock from observations of gross capital formation using the following relationship.

$$K_t = K_{t-1}(1 - \delta) + I_t \quad (1)$$

$K$  in the equation above represents the level of capital stock,  $\delta$  represents the rate of capital depreciation, and  $I_t$  refers to capital investment. Considering the characteristics of Egyptian investment and the literature, a 5% depreciation rate<sup>2</sup> is considered. The equation for calculating capital stock is given by

$$K_0 = I_0/(g + \delta) \quad (2)$$

$K_0$  and  $I_0$  are initial capital and investment, respectively.  $g$  is the average growth rate of investment.

### 4. The model and estimation

#### 4.1. The model

Because of difficulties in obtaining costs data, this paper employs a translog production function to model the causality relationship among various energy types and economic growth. Results from these models are then used to extract elasticities of substitution. The output – input relationship for the traditional static translog model and the nature of causality relationships are expressed in Eqs. (3)–(8) as follows:

$$\ln Y_t = \alpha_0 + \sum_i a_i \ln X_{it} + \frac{1}{2} \sum_i \sum_j a_{ij} \ln X_{it} \ln X_{jt} \quad (3)$$

$$\ln K_t = \alpha_0 + \sum_i a_i \ln X_{it} + \frac{1}{2} \sum_i \sum_j a_{ij} \ln X_{it} \ln X_{jt} \quad (4)$$

$$\ln L_t = \alpha_0 + \sum_i a_i \ln X_{it} + \frac{1}{2} \sum_i \sum_j a_{ij} \ln X_{it} \ln X_{jt} \quad (5)$$

$$\ln E_t = \alpha_0 + \sum_i a_i \ln X_{it} + \frac{1}{2} \sum_i \sum_j a_{ij} \ln X_{it} \ln X_{jt} \quad (6)$$

$$\ln N_t = \alpha_0 + \sum_i a_i \ln X_{it} + \frac{1}{2} \sum_i \sum_j a_{ij} \ln X_{it} \ln X_{jt} \quad (7)$$

$$\ln P_t = \alpha_0 + \sum_i a_i \ln X_{it} + \frac{1}{2} \sum_i \sum_j a_{ij} \ln X_{it} \ln X_{jt} \quad (8)$$

$Y_t$  in the above represents output,  $K_t$  represents capital,  $L_t$  represents labor,  $E_t$  represents electricity,  $N_t$  represents natural gas and  $P_t$  represents petroleum.  $\alpha_0$  is a technical parameter,  $X_{it}$  and  $X_{jt}$  represent

<sup>2</sup> This 5% capital depreciation rate is derived by considering the average value of Egyptian capital depreciation in 2014, that is 6% (PWT, 2016), and the capital depreciation in 2010, that is 4% (Hevia and Loayza, 2011). This rate is reasonable especially considering that 5% is popularly used in the literature for developing countries.

inputs  $i$  and  $j$ , respectively at time  $t$ ,  $a_i$  and  $a_{ij}$  are technical change parameters.

Notwithstanding, since causality is a dynamic concept, it becomes necessary to apply dynamic estimation procedures to the models. For this purpose, we incorporate lag-dependent variables into the system of equations in (3–8) (see Urga and Walters, 2003; Li et al., 2017). For example, incorporating a new variable “ $\ln Y_{t-1}$ ” in Eq. (3),  $\alpha_{Y_{t-1}}$ ,  $\alpha_K$ ,  $\alpha_L$ ,  $\alpha_E$ ,  $\alpha_N$  and  $\alpha_P$  are replaced by:

$$\begin{aligned} & \beta_{Y_{t-1}} + \beta_{Y_{t-1}K} \ln K + \beta_{Y_{t-1}L} \ln L + \beta_{Y_{t-1}E} \ln E + \beta_{Y_{t-1}N} \ln N + \beta_{Y_{t-1}P} \ln P \\ & + 2\beta_{Y_{t-1}Y_{t-1}} \ln Y_{t-1}, \\ & \beta_K + \beta_{KY_{t-1}} \ln Y_{t-1} + \beta_{KL} \ln L + \beta_{KE} \ln E + \beta_{KN} \ln N + \beta_{KP} \ln P \\ & + 2\beta_{KK} \ln K, \\ & \beta_L + \beta_{LY_{t-1}} \ln Y_{t-1} + \beta_{LK} \ln K + \beta_{LE} \ln E + \beta_{LN} \ln N + \beta_{LP} \ln P \\ & + 2\beta_{LL} \ln L, \\ & \beta_E + \beta_{EY_{t-1}} \ln Y_{t-1} + \beta_{EK} \ln K + \beta_{EL} \ln L + \beta_{EN} \ln N + \beta_{EP} \ln P \\ & + 2\beta_{EE} \ln E, \\ & \beta_N + \beta_{NY_{t-1}} \ln Y_{t-1} + \beta_{NK} \ln K + \beta_{NE} \ln E + \beta_{NL} \ln L + \beta_{NP} \ln P \\ & + 2\beta_{NN} \ln N, \text{ and} \\ & \beta_P + \beta_{PY_{t-1}} \ln Y_{t-1} + \beta_{PK} \ln K + \beta_{PE} \ln E + \beta_{PN} \ln N + \beta_{PL} \ln L \\ & + 2\beta_{PP} \ln P, \text{ respectively.} \end{aligned}$$

Therefore, incorporating the constant  $\beta_0$ , total output in the previous year ( $Y_{t-1}$ ), and the random error term  $u_t$ , Eq. (3) can be rewritten as:

$$\begin{aligned} \ln Y_t = & \beta_0 + \beta_{Y_{t-1}} \ln Y_{t-1} + \beta_K \ln K_t + \beta_L \ln L_t + \beta_P \ln P_t + \beta_E \ln E_t + \beta_N \ln N_t \\ & + \beta_{Y_{t-1}K} \ln Y_{t-1} \ln K_t + \beta_{Y_{t-1}L} \ln Y_{t-1} \ln L_t + \beta_{Y_{t-1}P} \ln Y_{t-1} \ln P_t \\ & + \beta_{Y_{t-1}E} \ln Y_{t-1} \ln E_t + \beta_{Y_{t-1}N} \ln Y_{t-1} \ln N_t \\ & + \beta_{KY_{t-1}} \ln K_t \ln Y_{t-1} + \beta_{KL} \ln K_t \ln L_t + \beta_{KP} \ln K_t \ln P_t + \beta_{KE} \ln K_t \ln E_t \\ & + \beta_{KN} \ln K_t \ln N_t \\ & + \beta_{LY_{t-1}} \ln L_t \ln Y_{t-1} + \beta_{LN} \ln L_t \ln N_t + \beta_{LE} \ln L_t \ln E_t + \beta_{LP} \ln L_t \ln P_t \\ & + \beta_{LE} \ln L_t \ln E_t \\ & + \beta_{Y_{t-1}Y_{t-1}} (\ln Y_{t-1})^2 + \beta_{KK} (\ln K_t)^2 + \beta_{LL} (\ln L_t)^2 + \beta_{PP} (\ln P_t)^2 + \beta_{EE} (\ln E_t)^2 \\ & + \beta_{NN} (\ln N_t)^2 \end{aligned} \quad (9)$$

The adjustments in Eq. (9) are also carried over to Eqs. (4)–(8). In order to measure these results continuously, we follow Li et al. (2017) by applying the following state equation given by

$$\beta_t = \gamma \beta_{t-1} + \varepsilon \quad (10)$$

From Eq. (10), we establish a dynamic estimation and the estimates are allow to change with the study period.

After estimating the direction of causality, the substitution elasticities between two inputs are obtained by solving:

$$\sigma_{ij} = \left[ 1 + \frac{-\beta_{ij} + (\eta_i/\eta_j)\beta_{jj}}{-\eta_i + \eta_j} \right]^{-1} \quad (11)$$

For substitution between petroleum and electricity

$$\sigma_{PE} = \left[ 1 + \frac{-\beta_{PE} + (\eta_P/\eta_E)\beta_{EE}}{-\eta_P + \eta_E} \right]^{-1} \quad (12)$$

For substitution between petroleum and natural gas

$$\sigma_{PN} = \left[ 1 + \frac{-\beta_{PN} + (\eta_P/\eta_N)\beta_{NN}}{-\eta_P + \eta_N} \right]^{-1} \quad (13)$$

For substitution between natural gas and electricity



$$\sigma_{NE} = \left[ 1 + \frac{-\beta_{NE} + (\eta_N/\eta_E)\beta_{EE}}{-\eta_N + \eta_E} \right]^{-1} \quad (14)$$

#### 4.2. Estimation

Considering our data and the presence of interaction terms in the models, the possibility of multicollinearity seems likely. In order to avoid spurious results, there is a need to adopt modeling techniques which are robust to multicollinearity problem. Hence, ridge regression technique proposed by Hoerl and Kennard (1970a, 1970b) comes in handy. The optimal value of the ridge parameter is obtained using the ridge trace plot approach. This technique is combined with Kalman Filter Method to facilitate dynamic modeling. Since these approaches are popularly documented in the literature, technical details are avoided of conserve space. For recent application of the approach, interested readers are referred to Wesseh and Lin (2016a, 2016b, 2016c) and Wesseh and Lin (2017).

### 5. Results and discussion

#### 5.1. Results

We begin with correlation analysis based on Kmenta (1986) to confirm the presence of multicollinearity in the model. Correlation results, not presented to conserve space, demonstrate significant level of multicollinearity. These results are not surprising due to the presence of interaction and square terms in the models. For this reason, the appropriateness of Ridge regression as an estimation technique for our models is justifiable.

Next, we test the stationarity property of the data. Although this should not be an issue since all the time series have been log-linearized and normalized around their means, it is important to show that all variables applied to the models are stationary. These results, as demonstrated in Table 2, suggest that all normalized variables applied to the models are stationary. Hence, standard Ridge regression should produce reliable estimates.

To progress with Ridge regression, we must first determine an optimal value for the Ridge parameter. We adopt the Ridge trace plot approach and this result is shown in Fig. 2. After studying Fig. 2, we select 0.6 as the Ridge parameter.

From the Ridge estimation, causality results are presented in Table 3. These results show a one-way causality relationship from electricity consumption to other energy forms (i.e. petroleum and natural gas) and a two-way relationship between all energy forms (i.e. electricity, petroleum and natural gas) and economic growth. Hence, our use of a production-based approach to causality is supportive of findings which show bidirectional causality between energy consumption and economic growth.

Using computed output elasticities, substitution elasticities between various energy pairs are then computed and reported in Fig. 3. These results are positive for all energy pairs, and hence, suggesting substitution potential between petroleum and electricity, natural gas and electricity, as well as petroleum and natural gas. It has to be said that the higher the elasticity of substitution, the easier it is to substitute the

variables in question. This implies that periods corresponding to higher substitution elasticities represent periods in which substitution is easier.

Considering the importance of various energy forms for Egyptian economic growth and the substitution potential between all energy pairs, an attempt is made to estimate the level of technological progress with which each energy form is used. Using the change over time ( $t^*$ ) to represent technical change as was suggested by Wesseh and Lin (2016a), we define the following relationship for both non-input dependent and input dependent technical change:

$$\gamma_1 t^* + \frac{1}{2} \gamma_2 t^{*2} + \sum_{j=1}^J \beta_j \ln x_{jt} t^* \quad (15)$$

In the above expression,  $\gamma_1$  and  $\gamma_2$  are the non-input dependent parameters representing technical change and the  $\beta_j$ 's are the input dependent parameters representing technical change. The estimated change in output with respect to a change in technical change is given by:

$$\left. \frac{d \ln Y_t}{dt^*} \right|_{dx_j=0} = t^* + \gamma_2 t^{*2} + \sum_{j=1}^J \beta_j \ln x_{jt} t^* \quad (16)$$

As may be observed from the results reported in Fig. 4, all the  $\beta_j$ 's are greater than zero indicating that technical progress is mainly input-driven and varies between 4.5% and 7.5%. Given this level of technical change, attempt is also made to estimate the mitigation potential arising from energy substitution.

One must not forget that Egypt has one of the highest energy subsidies in the world and, as we show in Fig. 1, the level of CO<sub>2</sub> emissions in the country has increased considerably since the year 1980. For this reason, it becomes necessary to examine the manner in which inter-fuel substitution in Egypt impacts on CO<sub>2</sub> emissions. As a case study, we investigate how a certain increase in capital investment associated with natural gas (for the purpose of substitution between petroleum and natural gas) would reduce the level of CO<sub>2</sub> emissions. In order to do this, we employ the approach in Lin and Xie (2014) in which results of substitution elasticities obtained between petroleum and natural gas are applied to different scenarios. The scenarios we study correspond to a 5% and 10% increase in capital investment tie to natural gas (for the purpose of reducing investment in petroleum) over the periods 2010, 2013 and 2016 using petroleum consumption and CO<sub>2</sub> emissions data.

These results, as presented in Table 4, suggest that for a 5% and 10% increase in investment linked to petroleum reduction technologies, this would lead to a corresponding reduction in petroleum use by 120,876, 145,186, 160,100 and 248,666, 355,104, 462,779 BTU for the years 2010, 2013 and 2016, respectively. As a result of this reduction in petroleum consumption, the level of CO<sub>2</sub> emissions under the 5% investment scenario reduces by 1.5026, 1.9716 and 2.2035 million metric tons corresponding to the years 2010, 2013 and 2016, respectively. Under the 10% investment scenario, there is a corresponding reduction in the level of CO<sub>2</sub> emissions by 2.5732, 4.0222, and 4.5116 million metric tons for the years 2010, 2013 and 2016, respectively. These results suggest that substituting petroleum for natural gas has the potential of reducing CO<sub>2</sub> emissions in Egypt without negatively affecting the level of economic growth. It should be noted that the kind of substitution here is proportional. This means that the subsequent increase in natural gas use as a result of reduction in petroleum use corresponds to the magnitude of petroleum reduction and its contribution to economic growth. Furthermore, environmental benefits are internalized, and hence, the cost savings from environmental clean-up should offset the costs associated with technology switching.

#### 5.2. Discussion

In the paragraphs that follow, we discuss some of the major findings reported in this study. We begin from the impacts of electricity, natural gas and petroleum on the Egyptian economy to the possibilities of

**Table 2**  
Stationarity analysis (normalized variables).

|                 | Augmented Dickey–Fuller (ADF) | Phillips–Perron (PP) |
|-----------------|-------------------------------|----------------------|
| Electricity     | −2.831***                     | −2.784***            |
| Natural gas     | −4.158***                     | −3.206***            |
| Petroleum       | −4.307***                     | −2.801***            |
| Economic growth | −2.724***                     | −2.686***            |

\*\*\* Indicates stationarity at the 1% level of significance.

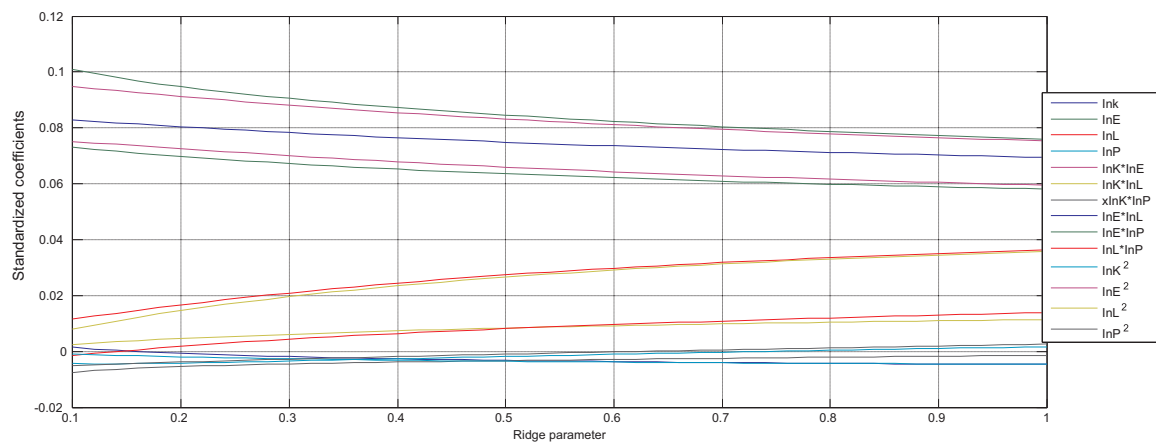


Fig. 2. Ridge trace plot.

**Table 3**  
Causality analysis<sup>a</sup>.

| X variable (causality) | Y variable (causality) |             |           |                 |
|------------------------|------------------------|-------------|-----------|-----------------|
|                        | Electricity            | Natural gas | Petroleum | Economic growth |
| Electricity            | –                      | 2.576**     | 2.571**   | 3.894**         |
| Natural gas            | 1.361                  | –           | 1.374     | 2.487**         |
| Petroleum              | 1.211                  | 0.189       | –         | 2.788**         |
| Economic growth        | 3.876**                | 2.480**     | 2.976**   | –               |

\*\*\*Indicates rejection of the 'no causality' hypothesis at the 10% significance level.

<sup>a</sup> Figures reported indicate F-Statistics.

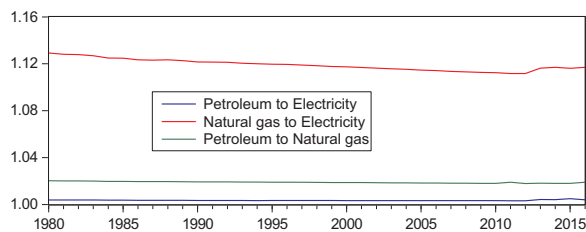


Fig. 3. Substitution elasticities.

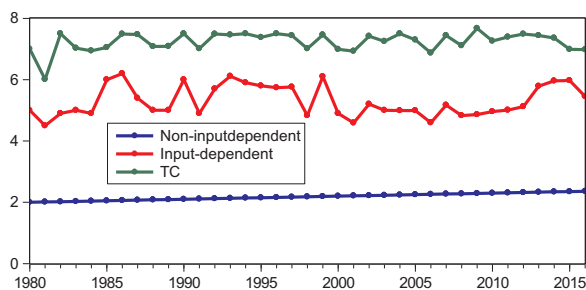


Fig. 4. State of technological progress.

substituting one fuel for another without affecting economic output. We also discuss the level of technological progress of the various energy inputs and address the potential that Egypt has to mitigate CO<sub>2</sub> emissions as a result of energy substitution efforts.

To begin with, our findings suggest a two-way relationship between all energy forms (i.e. electricity, petroleum and natural gas) and economic growth. This reliance of the Egyptian economy on energy consumption of various forms demonstrates the importance of energy expansion policies for Egypt. As a country that is still far from achieving its full potential for maximum resources mobilization and output, energy is a critical factor for achieving high growth and prosperity, and as

**Table 4**  
Petroleum reduction and CO<sub>2</sub> emission mitigation (Egypt).

| Year  | Petroleum reduction (BTU) | CO <sub>2</sub> emissions reduction (million metric tons) |
|---|---------------------------|---|
| <b>Scenario 1</b><br>(Increasing natural gas capital investment by 5%)  |                           |   |
| 2010  | 120,876                   | 1.5026  |
| 2013  | 145,186                   | 1.9716  |
| 2016  | 160,100                   | 2.2035  |
| <b>Scenario 2</b><br>(Increasing natural gas capital investment by 10%) |                           |   |
| 2010  | 248,666                   | 2.5732  |
| 2013  | 355,104                   | 4.0222  |
| 2016  | 462,779                   | 4.5116  |

such, any implementation of energy conservation policies aimed at mitigating the adverse effects of climate change will have to be treated with caution. In other words, what this means is that efforts to reduce energy use by reducing energy subsidies and budgetary allotments for energy consumption could pose some risk of constraining the level of economic growth in Egypt. However, findings of substitution possibilities between petroleum and electricity, natural gas and electricity, and petroleum and natural gas imply that subsidies removal on one energy form (i.e. the one considered to be more environmentally damaging) could give rise to an increased consumption of another energy form (i.e. the one considered to be more environmentally friendly), and hence, neutralize the risk of decline in the level of economic growth. For instance, with electricity and natural gas being substitutes for petroleum, the types of substitution here will involve industries switching from petroleum use in their production process towards more use of electricity and natural gas. In this case, the government can promote more use of electricity and natural gas and less petroleum by adopting fiscal policies like; removal of all petroleum subsidies, price ceilings, taxes and creating an enabling environment for the competitive pricing of electricity and natural gas. Notwithstanding, one has to recognize that in order for an increased use of electricity (as opposed to petroleum) to be able to bring environmental benefits, then the source of generating electricity (fossil sources or renewable energy sources) as well as the responds at which industries will react to any switch becomes important factors. Also, in order to ensure that the full benefits or more electricity use are achieved, care has to be taken to endure the availability of electricity to meet demand. Furthermore, any switch from one energy form to another (say petroleum to electricity or petroleum to natural gas) would require some level of technology and capital expenditure on new machineries, technical personnel upgrade and electrical installations. Therefore, in order to simplify the adjustment process for various industries, policy makers or practitioners might be

required to formulate cost intervention policies to minimize capital expenditure. These policies could come in the form of lower taxes, capital expenditure subsidies, and provision of electricity infrastructure which will help cut the cost of industries expenditure on electricity infrastructure to avoid the cost being passed on to the final consumer in the form of price increase. Again, these must be done to avoid industrial energy rebound effect. Since the size of companies and industries also play a role in adjusting to structural changes as bigger industries are more likely to adjust easily and faster (Zhang and Wang, 2008), there might be a need for the Egyptian government to strengthen its merger control agencies by formulating clear merger policies since the switch from petroleum to more use of electricity and natural gas will put the smaller enterprises to productivity efficiency disadvantage which will compel the smaller enterprises to form a merger with their bigger counterparts. This will require government merger support policies for a fair agreement between and among various parties.

Finally, the results of this study also show that the state of technological progress is input-dependent and less than 9% at its maximum. This provides insights on the immense opportunities for mitigating CO<sub>2</sub> emissions that could arise from innovation in various energy technologies in Egypt, especially those relating to electricity, natural gas and petroleum. This potential is evident when one looks at the results from this study which point to the amount of CO<sub>2</sub> emissions that is reduced as a result of substituting petroleum for natural gas. The idea is that with higher levels of energy efficiency driven by increased innovation in various energy technologies, there could be even higher CO<sub>2</sub> emissions benefits emanating from inter-fuel substitution in Egypt.

## 6. Conclusions

In this study, we develop a translog-causality-based approach to energy and economic growth modeling in order to study the direction of causation between electricity, natural gas, petroleum and economic growth in Egypt. Subsequently, these results are used to estimate the substitution possibilities of these different energy types and to quantify the mitigation potential arising from the substitution of one fuel for another. Our applied production approach does not only define a definite relationship between output and input, but it also incorporates the interactions among various energy forms and the level of technical progress with which these inputs are used. Because of multicollinearity issues in the model, ridge regression techniques are used to estimate the parameters of the models, and therefore, control for this phenomenon.

The modeling exercises in this study present several findings. First, our results on energy and economy show a unidirectional causality relationship from electricity consumption to other energy forms (i.e. petroleum and natural gas) and a two-way relationship between all energy forms (i.e. electricity, petroleum and natural gas) and economic growth. Second, using computed output elasticities from the models, substitution elasticities between various energy pairs are computed and these results suggest high substitution possibilities between petroleum and electricity, natural gas and electricity, as well as petroleum and natural gas. This substitutability between various fuel pairs imply that Egypt has the potential of growing its economy on a limited use of petroleum (and to some extent natural gas) and could as well save its huge budget allocation for petroleum use and subsidies. Third, the state of technical progress in Egypt is mainly input-driven and a bit slow varying between 4.5% and 7.5%. Finally, there appears to be substantial CO<sub>2</sub> emissions mitigation benefits of inter-fuel substitution in Egypt in the range of 1.5 and 2.2 million metric tons under the 5% investment scenario and 2.5 and 4.5 million metric tons under the 10% investment scenario.

These results have important policy implications for Egypt. First, energy conservation policies on one fuel type (considered to be more polluting) would result in an increased use of another fuel type (considered to be cleaner) and this will have no adverse effect on the level of economic growth. In other words, policy makers in Egypt have the

leverage of imposing taxes and quotas on dirty fuels and enjoying less environmental damages without running the risk of suffering economic decline. Second, merger policies might be required in order to boost the sizes of smaller industries to levels that would increase their capacities to adjust easily to structural changes associated with the switch in technologies arising from inter-fuel substitution. Finally, the slow rate of technical progress and biased nature of technical change implies that Egypt has a huge potential for reducing the level of CO<sub>2</sub> emissions by enhancing energy efficiency through innovation in various energy technologies, especially electricity, natural gas and petroleum.

In summary, our production-based approach to causality, which accounts for energy substitution and technical change, has supported a bidirectional relationship between energy consumption and economic growth. Also, the models have shown immense environmental benefits from inter-fuel substitution and suggest an even higher mitigation potential for the future if innovations are carried out in various energy technologies.

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